IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of:	Mohammed Islam
Serial No.:	10/005/472
Filing Date:	November 16, 2001
Title:	MULTI-STAGE OPTICAL AMPLIFIER AND BROADBAND COMMUNICATION SYSTEM

Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

THIRD PRELIMINARY AMENDMENT

Prior to the initial review of this provisional utility continuation patent application entitled "Multi-Stage Optical Amplifier and Broadband Communication System" by Mohammed Islam, please amend the application as follows:

IN THE CLAIMS

For the convenience of the Examiner, a clean copy of all pending claims of the present Application is shown below whether or not an amendment has been made. Appendix A attached hereto contains a marked-up version of any amended claims, showing the amendments to those claims. Please amend the claims as follows.

1. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s, and a pump source that produces one or more pump wavelengths λ_p, wherein the one or more pump wavelengths λ_p are less than at least a portion of the plurality of signal wavelengths λ_s, at least a portion of the plurality of signal wavelengths λ_s of the first Raman amplifier fiber having an optical noise figure of less than 8 dB and less than an optical noise figure of the second Raman amplifier fiber, and at least a portion of the plurality of signal wavelengths λ_s, of the second Raman amplifier fiber having a gain level of at least 5 dB;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

2. The multi-stage optical amplifier of claim 1, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

3. The multi-stage optical amplifier of claim 1, wherein the pump shunt is coupled to the signal input port and the signal output port.

4. The multi-stage optical amplifier of claim 1, further comprising:

a distributed Raman amplifier coupled to the signal input port.

5. The multi-stage optical amplifier of claim 4, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

6. The multi-stage optical amplifier of claim 1, wherein the first and second lengths of Raman amplifier fiber each have a length greater than or equal to 200m.

7. The multi-stage optical amplifier of claim 1, wherein the one or more pump wavelengths λ_p are in the range of 1300 to 1530 nm.

8. The multi-stage optical amplifier of claim 1, wherein the plurality of signal wavelengths λ_s is in the range of 1430 to 1530 nm.

9. The multi-stage optical amplifier of claim l, wherein the first lossy member is an optical isolator.

10. The multi-stage optical amplifier of claim 1, wherein the first lossy member is an add/drop multiplexer.

11. The multi-stage optical amplifier of claim 1, wherein the first lossy member is a gain equalization member.

12. The multi-stage optical amplifier of claim 1, wherein the first lossy member is a dispersion compensation element.

13. The multi-stage optical amplifier of claim 1, wherein at least a portion of at least one of the first and second Raman amplifier fibers is a dispersion compensating fiber.

14. The multi-stage optical amplifier of claim 13, wherein at least a portion of the first and second Raman amplifier fibers are dispersion compensating fibers.

15. The multi-stage optical amplifier of claim 1, wherein the second length of amplifier fiber has a higher gain than the first length of amplifier fiber.

16. The multi-stage optical amplifier of claim 3, further comprising:

at least one WDM coupler to couple a pump path from the signal input port to the signal output port.

17. The multi-stage optical amplifier of claim 1, further comprising:

a pump source coupled to the pump input port.

18. The multi-stage optical amplifier of claim 1, further comprising:

at least one laser diode pump source coupled to the pump input port.

19. The multi-stage optical amplifier of claim 1, further comprising:

a second lossy member coupled to the pump shunt.

20. The multi-stage optical amplifier of claim 1, wherein the pump shunt includes an optical fiber.

21. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s, and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, and an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber that is less than the one or more pump wavelengths λ_p;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

22. The multi-stage optical amplifier of claim 21, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

23. The multi-stage optical amplifier of claim 21, wherein the pump shunt is coupled to the signal input port and the signal output port.

24. The multi-stage optical amplifier of claim 21, wherein optical fiber cut-off wavelengths of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are less than the one or more pump wavelengths λ_p.

25. The multi-stage optical amplifier of claim 21, further comprising:

a distributed Raman amplifier coupled to the signal input port.

26. The multi-stage optical amplifier of claim 25, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

27. The multi-stage optical amplifier of claim 21, wherein the first and second lengths of Raman amplifier fiber each have a length greater than or equal to 200m.

28. The multi-stage optical amplifier of claim 21, wherein the one or more pump wavelengths λ_p are in the range of 1300 to 1530 nm.

29. The multi-stage optical amplifier of claim 21, wherein the plurality of signal wavelengths λ_s is in the range of 1430 to 1530 run.

30. The multi-stage optical amplifier of claim 21, wherein the first lossy member is an optical isolator.

31. The multi-stage optical amplifier of claim 21, wherein the first lossy member is an add/drop multiplexer.

32. The multi-stage optical amplifier of claim 21, wherein the first lossy member is a gain equalization member.

33. The multi-stage optical amplifier of claim 21, wherein the first lossy member is a dispersion compensation element.

34. The multi-stage optical amplifier of claim 21, wherein at least a portion of at least one of the first and second Raman amplifier fibers is a dispersion compensating fiber.

35. The multi-stage optical amplifier of claim 34, wherein at least a portion of the first and second Raman amplifier fibers are dispersion compensating fibers.

36. The multi-stage optical amplifier of claim **[1]<u>21</u>**, wherein the second length of amplifier fiber has a higher gain than the first length of amplifier fiber.

37. The multi-stage optical amplifier of claim **[1]21**, further comprising: at least one WDM coupler to couple a pump path from the signal input port to the signal output port.

38. The multi-stage optical amplifier of claim **[1]21**, further comprising: a pump source coupled to the pump input port.

39. The multi-stage optical amplifier of claim **[1]21**, further comprising: at least one laser diode pump source coupled to the pump input port.

40. The multi-stage optical amplifier of claim **[1]21**, further comprising: a second lossy member coupled to the pump shunt.

41. The multi-stage optical amplifier of claim **[1]21**, wherein the pump shunt includes an optical fiber.

42. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

43. The multi-stage optical amplifier of claim 42, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

44. The multi-stage optical amplifier of claim 42, wherein an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is less than the one or more pump wavelengths λ_p.

45. The multi-stage optical amplifier of claim 42, wherein at least a portion of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are dispersion compensating fibers.

46. The multi-stage optical amplifier of claim 42, wherein the dispersion compensating fiber has a magnitude of dispersion of at least 50 psec/(nm) (km) for at least a portion of the plurality of signal wavelengths λ_s.

47. The multi-stage optical amplifier of claim 42, wherein the dispersion compensating fiber has a magnitude of dispersion less than 50 psec/(nm) (km) for at least a portion of the plurality of signal wavelengths λ_s.

48. The multi-stage optical amplifier of claim 42, further comprising:

a distributed Raman amplifier coupled to the signal input port.

49. The multi-stage optical amplifier of claim 48, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

50. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction;

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

at least a first pump source coupled to pump input port, the at least first pump source including multiple pump sources with outputs that are combined using at least one of wavelength and polarization multiplexing.

51. The multi-stage optical amplifier of claim 50, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

52. The multi-stage optical amplifier of claim 50, wherein the pump shunt is coupled to the signal input port and the signal output port.

53. The multi-stage optical amplifier of claim 50, wherein the at least first pump source includes multiple pump sources with outputs that are combined using wavelength and polarization multiplexing.

54. The multi-stage optical amplifier of claim 50, further comprising:

a distributed Raman amplifier coupled to the signal input port.

55. The multi-stage optical amplifier of claim 54, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

56. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber with a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, wherein the one or more pump wavelengths λ_p are less than at least a portion of the plurality of signal wavelengths λ_s, at least a portion of the plurality of wavelengths λ_s, of the first Raman amplifier fiber having an optical noise figure of less than 8 dB and less than an optical noise figure of the second Raman amplifier fiber, and at least a portion of the plurality of signal wavelengths λ_s, of the second Raman amplifier fiber having a gain level of at least 5 dB;

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

57. The multi-stage optical amplifier system of claim 56, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

58. The multi-stage optical amplifier system of claim 56, wherein the pump shunt is coupled to the signal input port and the signal output port.

59. The multi-stage optical amplifier system of claim 56, further comprising:

a distributed Raman amplifier coupled to the signal input port.

60. The multi-stage optical amplifier system of claim 59, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

61. The multi-stage optical amplifier system of claim 56, wherein the multi-stage optical amplifier is an in-line amplifier.

62. The multi-stage optical amplifier system of claim 56, wherein the multi-stage optical amplifier is a booster amplifier.

63. The multi-stage optical amplifier system of claim 56, wherein the multi-stage optical amplifier is a pre-amplifier.

64. The multi-stage optical amplifier system of claim 56, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

65. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier, including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and

configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, and an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber that is less than the one or more pump wavelengths λ_p,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

66. The multi-stage optical amplifier system of claim 65, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

67. The multi-stage optical amplifier system of claim 65, wherein the pump shunt is coupled to the signal input port and the signal output port.

68. The multi-stage optical amplifier system of claim 65, wherein optical fiber cut-off wavelengths of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are less than the one or more pump wavelengths λ_p.

69. The multi-stage optical amplifier system of claim 65, further comprising: a distributed Raman amplifier coupled to the signal input port.

70. The multi-stage optical amplifier system of claim 69, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

71. The multi-stage optical amplifier system of claim 69, wherein the multi-stage optical amplifier is an in-line amplifier.

72. The multi-stage optical amplifier system of claim 69, wherein the multi-stage optical amplifier is a booster amplifier.

73. The multi-stage optical amplifier system of claim 69, wherein the multi-stage optical amplifier is a pre-amplifier.

74. The multi-stage optical amplifier system of claim 69, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

75. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

76. The multi-stage optical amplifier system of claim 75, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

77. The multi-stage optical amplifier system of claim 75, wherein an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is less than the one or more pump wavelengths XP.

78. The multi-stage optical amplifier system of claim 75, wherein at least a portion of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are dispersion compensating fibers.

79. The multi-stage optical amplifier system of claim 75, wherein the dispersion compensating fiber has a magnitude of dispersion greater than 50 psec/(nm) -(km) for at least a portion of the plurality of signal wavelengths λ_s.

80. The multi-stage optical amplifier system of claim 75, wherein the dispersion compensating fiber has a magnitude of dispersion less than, 50 psec/(nm) (km) for at least a portion of the plurality of signal wavelengths λ_s.

81. The multi-stage optical amplifier system of claim 75, further comprising:
a distributed Raman amplifier coupled to the signal input port.

82. The multi-stage optical amplifier system of claim 81, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

83. The multi-stage optical amplifier system of claim 75, wherein the multi-stage optical amplifier is an in-line amplifier.

84. The multi-stage optical amplifier system of claim 75, wherein the multi-stage optical amplifier is a booster amplifier.

85. The multi-stage optical amplifier system of claim 75, wherein the multi-stage optical amplifier is a pre-amplifier.

86. The multi-stage optical amplifier system of claim 75, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

87. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber,

at least a first pump source coupled to pump input port, the at least first pump source including multiple pump sources with outputs that are combined using at least one of wavelength and polarization multiplexing; and

a plurality of receivers coupled to the multi-stage optical amplifier.

88. The multi-stage optical amplifier system of claim 87, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

89. The multi-stage optical amplifier system of claim 87, wherein the pump shunt is coupled to the signal input port and the signal output port.

90. The multi-stage optical amplifier system of claim 87, wherein at least first pump source includes multiple pump sources with outputs that are combined using wavelength and polarization multiplexing.

91. The multi-stage optical amplifier system of claim 87, further comprising:

a distributed Raman amplifier coupled to the signal input port.

92. The multi-stage optical amplifier system of claim 91, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

93. The multi-stage optical amplifier system of claim 87, wherein the multi-stage optical amplifier is an in-line amplifier.

94. The multi-stage optical amplifier system of claim 87, wherein the multi-stage optical amplifier is a booster amplifier.

95. The multi-stage optical amplifier system of claim 87, wherein the multi-stage optical amplifier is a pre-amplifier.

96. The multi-stage optical amplifier system of claim 87, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

97. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a fiber with a selected small effective core area and high germanium doping to provide an enhancement of a Raman gain coefficient;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

98. The multi-stage optical amplifier of claim 97, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

99. The multi-stage optical amplifier of claim 97, wherein an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is less than the one or more pump wavelengths λ_p.

100. The multi-stage optical amplifier of claim 97, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber.

101. The multi-stage optical amplifier of claim 97, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber.

102. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths $\lambda_{s;}$

a multi-stage optical amplifier including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a fiber with a selected small effective core area and high germanium doping to provide an enhancement of a Raman gain coefficient,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

REMARKS

Early and favorable acceptance of this continuation application is respectfully requested.

Respectfully submitted,

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MARKED-UP VERSION OF THE CLAIMS

1. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s, and a pump source that produces one or more pump wavelengths λ_p, wherein the one or more pump wavelengths λ_p are less than at least a portion of the plurality of signal wavelengths λ_s, at least a portion of the plurality of signal wavelengths λ_s of the first Raman amplifier fiber having an optical noise figure of less than 8 dB and less than an optical noise figure of the second Raman amplifier fiber, and at least a portion of the plurality of signal wavelengths λ_s, of the second Raman amplifier fiber having a gain level of at least 5 dB;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

2. The multi-stage optical amplifier of claim 1, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

3. The multi-stage optical amplifier of claim 1, wherein the pump shunt is coupled to the signal input port and the signal output port.

4. The multi-stage optical amplifier of claim 1, further comprising:

a distributed Raman amplifier coupled to the signal input port.

5. The multi-stage optical amplifier of claim 4, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

6. The multi-stage optical amplifier of claim 1, wherein the first and second lengths of Raman amplifier fiber each have a length greater than or equal to 200m.

7. The multi-stage optical amplifier of claim 1, wherein the one or more pump wavelengths λ_p are in the range of 1300 to 1530 nm.

8. The multi-stage optical amplifier of claim 1, wherein the plurality of signal wavelengths λ_s is in the range of 1430 to 1530 nm.

9. The multi-stage optical amplifier of claim l, wherein the first lossy member is an optical isolator.

10. The multi-stage optical amplifier of claim 1, wherein the first lossy member is an add/drop multiplexer.

11. The multi-stage optical amplifier of claim 1, wherein the first lossy member is a gain equalization member.

12. The multi-stage optical amplifier of claim 1, wherein the first lossy member is a dispersion compensation element.

13. The multi-stage optical amplifier of claim 1, wherein at least a portion of at least one of the first and second Raman amplifier fibers is a dispersion compensating fiber.

14. The multi-stage optical amplifier of claim 13, wherein at least a portion of the first and second Raman amplifier fibers are dispersion compensating fibers.

15. The multi-stage optical amplifier of claim 1, wherein the second length of amplifier fiber has a higher gain than the first length of amplifier fiber.

16. The multi-stage optical amplifier of claim 3, further comprising:

at least one WDM coupler to couple a pump path from the signal input port to the signal output port.

17. The multi-stage optical amplifier of claim 1, further comprising:

a pump source coupled to the pump input port.

18. The multi-stage optical amplifier of claim 1, further comprising:

at least one laser diode pump source coupled to the pump input port.

19. The multi-stage optical amplifier of claim 1, further comprising:

a second lossy member coupled to the pump shunt.

20. The multi-stage optical amplifier of claim 1, wherein the pump shunt includes an optical fiber.

21. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s, and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, and an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber that is less than the one or more pump wavelengths λ_p;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

22. The multi-stage optical amplifier of claim 21, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

23. The multi-stage optical amplifier of claim 21, wherein the pump shunt is coupled to the signal input port and the signal output port.

24. The multi-stage optical amplifier of claim 21, wherein optical fiber cut-off wavelengths of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are less than the one or more pump wavelengths λ_p.

25. The multi-stage optical amplifier of claim 21, further comprising:

a distributed Raman amplifier coupled to the signal input port.

26. The multi-stage optical amplifier of claim 25, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

27. The multi-stage optical amplifier of claim **[1]21**, wherein the first and second lengths of Raman amplifier fiber each have a length greater than or equal to 200m.

28. The multi-stage optical amplifier of claim **[1]21**, wherein the one or more pump wavelengths λ_p are in the range of 1300 to 1530 nm.

29. The multi-stage optical amplifier of claim **[1]21**, wherein the plurality of signal wavelengths $\lambda_s$is in the range of 1430 to 1530 run.

30. The multi-stage optical amplifier of claim **[1]21**, wherein the first lossy member is an optical isolator.

31. The multi-stage optical amplifier of claim **[1]21**, wherein the first lossy member is an add/drop multiplexer.

32. The multi-stage optical amplifier of claim **[1]21**, wherein the first lossy member is a gain equalization member.

33. The multi-stage optical amplifier of claim **[1]21**, wherein the first lossy member is a dispersion compensation element.

34. The multi-stage optical amplifier of claim **[1]21**, wherein at least a portion of at least one of the first and second Raman amplifier fibers is a dispersion compensating fiber.

35. The multi-stage optical amplifier of claim 34, wherein at least a portion of the first and second Raman amplifier fibers are dispersion compensating fibers.

36. The multi-stage optical amplifier of claim **[1]21**, wherein the second length of amplifier fiber has a higher gain than the first length of amplifier fiber.

37. The multi-stage optical amplifier of claim **[1]21**, further comprising:

at least one WDM coupler to couple a pump path from the signal input port to the signal output port.

38. The multi-stage optical amplifier of claim **[1]21**, further comprising:

a pump source coupled to the pump input port.

39. The multi-stage optical amplifier of claim **[1]21**, further comprising:

at least one laser diode pump source coupled to the pump input port.

40. The multi-stage optical amplifier of claim **[1]21**, further comprising:

a second lossy member coupled to the pump shunt.

41. The multi-stage optical amplifier of claim **[1]21**, wherein the pump shunt includes an optical fiber.

42. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

43. The multi-stage optical amplifier of claim 42, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

44. The multi-stage optical amplifier of claim 42, wherein an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is less than the one or more pump wavelengths λ_p.

45. The multi-stage optical amplifier of claim 42, wherein at least a portion of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are dispersion compensating fibers.

46. The multi-stage optical amplifier of claim 42, wherein the dispersion compensating fiber has a magnitude of dispersion of at least 50 psec/(nm) (km) for at least a portion of the plurality of signal wavelengths λ_s.

47. The multi-stage optical amplifier of claim 42, wherein the dispersion compensating fiber has a magnitude of dispersion less than 50 psec/(nm) (km) for at least a portion of the plurality of signal wavelengths λ_s.

48. The multi-stage optical amplifier of claim 42, further comprising:
a distributed Raman amplifier coupled to the signal input port.

49. The multi-stage optical amplifier of claim 48, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

50. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction;

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

at least a first pump source coupled to pump input port, the at least first pump source including multiple pump sources with outputs that are combined using at least one of wavelength and polarization multiplexing.

51. The multi-stage optical amplifier of claim 50, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

52. The multi-stage optical amplifier of claim 50, wherein the pump shunt is coupled to the signal input port and the signal output port.

53. The multi-stage optical amplifier of claim 50, wherein the at least first pump source includes multiple pump sources with outputs that are combined using wavelength and polarization multiplexing.

54. The multi-stage optical amplifier of claim 50, further comprising:

a distributed Raman amplifier coupled to the signal input port.

55. The multi-stage optical amplifier of claim 54, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

56. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber with a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, wherein the one or more pump wavelengths λ_p are less than at least a portion of the plurality of signal wavelengths λ_s, at least a portion of the plurality of wavelengths λ_s, of the first Raman amplifier fiber having an optical noise figure of less than 8 dB and less than an optical noise figure of the second Raman amplifier fiber, and at least a portion of the plurality of signal wavelengths λ_s, of the second Raman amplifier fiber having a gain level of at least 5 dB;

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

57. The multi-stage optical amplifier system of claim 56, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

58. The multi-stage optical amplifier system of claim 56, wherein the pump shunt is coupled to the signal input port and the signal output port.

59. The multi-stage optical amplifier system of claim 56, further comprising:

a distributed Raman amplifier coupled to the signal input port.

60. The multi-stage optical amplifier system of claim 59, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

61. The multi-stage optical amplifier system of claim 56, wherein the multi-stage optical amplifier is an in-line amplifier.

62. The multi-stage optical amplifier system of claim 56, wherein the multi-stage optical amplifier is a booster amplifier.

63. The multi-stage optical amplifier system of claim 56, wherein the multi-stage optical amplifier is a pre-amplifier.

64. The multi-stage optical amplifier system of claim 56, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

65. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier, including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of **[tranmitters]**<u>**transmitters**</u> and

configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, and an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber that is less than the one or more pump wavelengths λ_p,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

66. The multi-stage optical amplifier system of claim 65, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

67. The multi-stage optical amplifier system of claim 65, wherein the pump shunt is coupled to the signal input port and the signal output port.

68. The multi-stage optical amplifier system of claim 65, wherein optical fiber cut-off wavelengths of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are less than the one or more pump wavelengths λ_p.

69. The multi-stage optical amplifier system of claim 65, further comprising:
a distributed Raman amplifier coupled to the signal input port.

70. The multi-stage optical amplifier system of claim 69, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

71. The multi-stage optical amplifier system of claim 69, wherein the multi-stage optical amplifier is an in-line amplifier.

72. The multi-stage optical amplifier system of claim 69, wherein the multi-stage optical amplifier is a booster amplifier.

73. The multi-stage optical amplifier system of claim 69, wherein the multi-stage optical amplifier is a pre-amplifier.

74. The multi-stage optical amplifier system of claim 69, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

75. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.

76. The multi-stage optical amplifier system of claim 75, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

77. The multi-stage optical amplifier system of claim 75, wherein an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is less than the one or more pump wavelengths XP.

78. The multi-stage optical amplifier system of claim 75, wherein at least a portion of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber are dispersion compensating fibers.

79. The multi-stage optical amplifier system of claim 75, wherein the dispersion compensating fiber has a magnitude of dispersion greater than 50 psec/(nm) -(km) for at least a portion of the plurality of signal wavelengths λ_s.

80. The multi-stage optical amplifier system of claim 75, wherein the dispersion compensating fiber has a magnitude of dispersion less than, 50 psec/(nm) (km) for at least a portion of the plurality of signal wavelengths λ_s.

81. The multi-stage optical amplifier system of claim 75, further comprising:
a distributed Raman amplifier coupled to the signal input port.

82. The multi-stage optical amplifier system of claim 81, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

83. The multi-stage optical amplifier system of claim 75, wherein the multi-stage optical amplifier is an in-line amplifier.

84. The multi-stage optical amplifier system of claim 75, wherein the multi-stage optical amplifier is a booster amplifier.

85. The multi-stage optical amplifier system of claim 75, wherein the multi-stage optical amplifier is a pre-amplifier.

86. The multi-stage optical amplifier system of claim 75, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

87. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber,

at least a first pump source coupled to pump input port, the at least first pump source including multiple pump sources with outputs that are combined using at least one of wavelength and polarization multiplexing; and

a plurality of receivers coupled to the multi-stage optical amplifier.

88. The multi-stage optical amplifier system of claim 87, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

89. The multi-stage optical amplifier system of claim 87, wherein the pump shunt is coupled to the signal input port and the signal output port.

90. The multi-stage optical amplifier system of claim 87, wherein at least first pump source includes multiple pump sources with outputs that are combined using wavelength and polarization multiplexing.

91. The multi-stage optical amplifier system of claim 87, further comprising: a distributed Raman amplifier coupled to the signal input port.

92. The multi-stage optical amplifier system of claim 91, wherein at least a portion of the pump shunt is positioned between the distributed Raman amplifier and the signal input port.

93. The multi-stage optical amplifier system of claim 87, wherein the multi-stage optical amplifier is an in-line amplifier.

94. The multi-stage optical amplifier system of claim 87, wherein the multi-stage optical amplifier is a booster amplifier.

95. The multi-stage optical amplifier system of claim 87, wherein the multi-stage optical amplifier is a pre-amplifier.

96. The multi-stage optical amplifier system of claim 87, wherein the plurality of receivers are directly coupled to the multi-stage optical amplifier.

97. A multi-stage optical amplifier, comprising:

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber configured to be coupled to a signal source that produces a plurality of signal wavelengths λ_s and a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a fiber with a selected small effective core area and high germanium doping to provide an enhancement of a Raman gain coefficient;

a signal input port coupled to the optical fiber;

a signal output port coupled to the optical fiber;

a pump input port coupled to the optical fiber;

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction; and

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber.

98. The multi-stage optical amplifier of claim 97, wherein the pump input port is positioned between the first and second lengths of Raman amplifier fiber.

99. The multi-stage optical amplifier of claim 97, wherein an optical fiber cut-off wavelength of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is less than the one or more pump wavelengths λ_p.

100. The multi-stage optical amplifier of claim 97, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber.

101. The multi-stage optical amplifier of claim 97, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a dispersion compensating fiber.

102. A multi-stage optical amplifier system, comprising:

a plurality of transmitters that produce a plurality of signal wavelengths λ_s;

a multi-stage optical amplifier including,

an optical fiber including a first length of Raman amplifier fiber and a second length of Raman amplifier fiber, the optical fiber coupled to the plurality of transmitters and configured to be coupled to a pump source that produces one or more pump wavelengths λ_p, the one or more pump wavelengths λ_p being less than at least a portion of the plurality of signal wavelengths λ_s, wherein at least a portion of at least one of the first length of Raman amplifier fiber and the second length of Raman amplifier fiber is a fiber with a selected small effective core area and high germanium doping to provide an enhancement of a Raman gain coefficient,

a signal input port coupled to the optical fiber,

a signal output port coupled to the optical fiber,

a pump input port coupled to the optical fiber,

a first lossy member coupled to the optical fiber and positioned between the first and second lengths of Raman amplifier fiber, the first lossy member being lossy in at least one direction,

a pump shunt coupled to the optical fiber, wherein at least a portion of the one or more pump wavelengths λ_p is coupled between the first length of Raman amplifier fiber and the second length of Raman amplifier fiber; and

a plurality of receivers coupled to the multi-stage optical amplifier.